56 MHz SRF upgrade and commissioning

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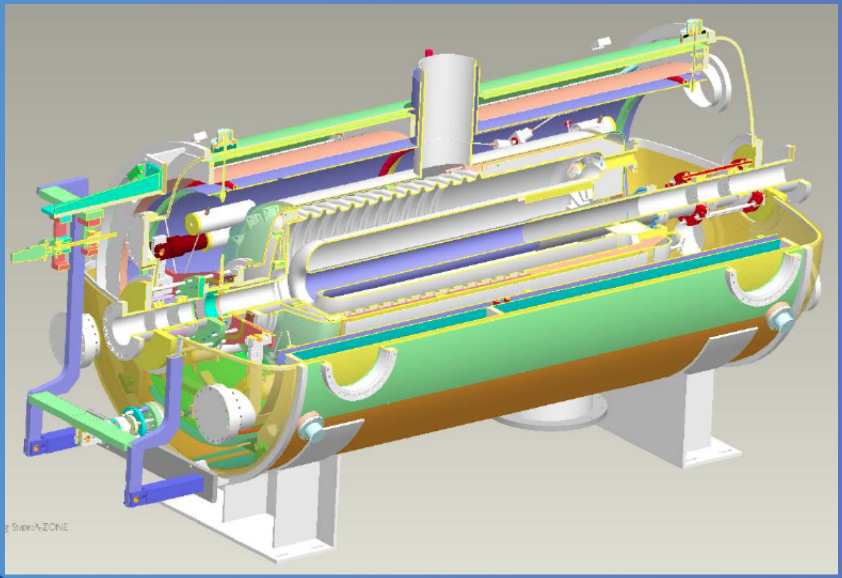
November 3, 2011



C-AD MAC-08
BNL • November2 – 3, 2011

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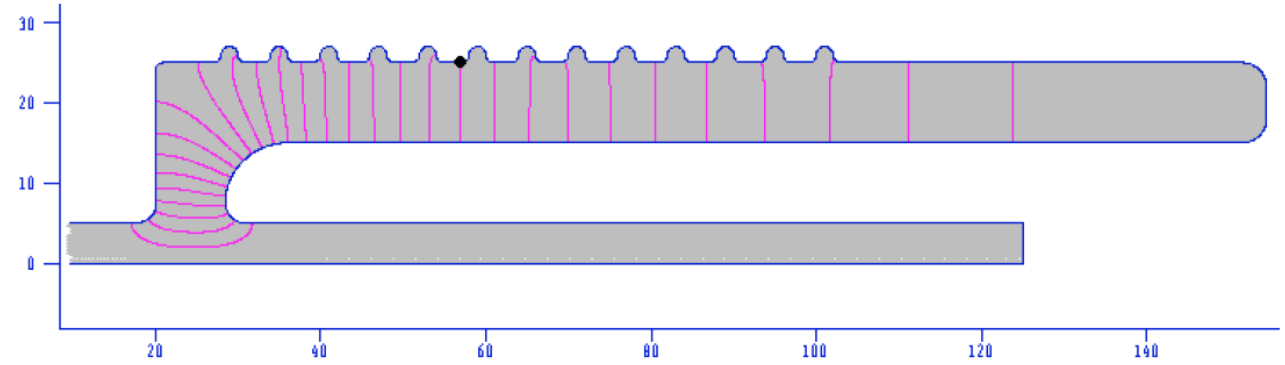
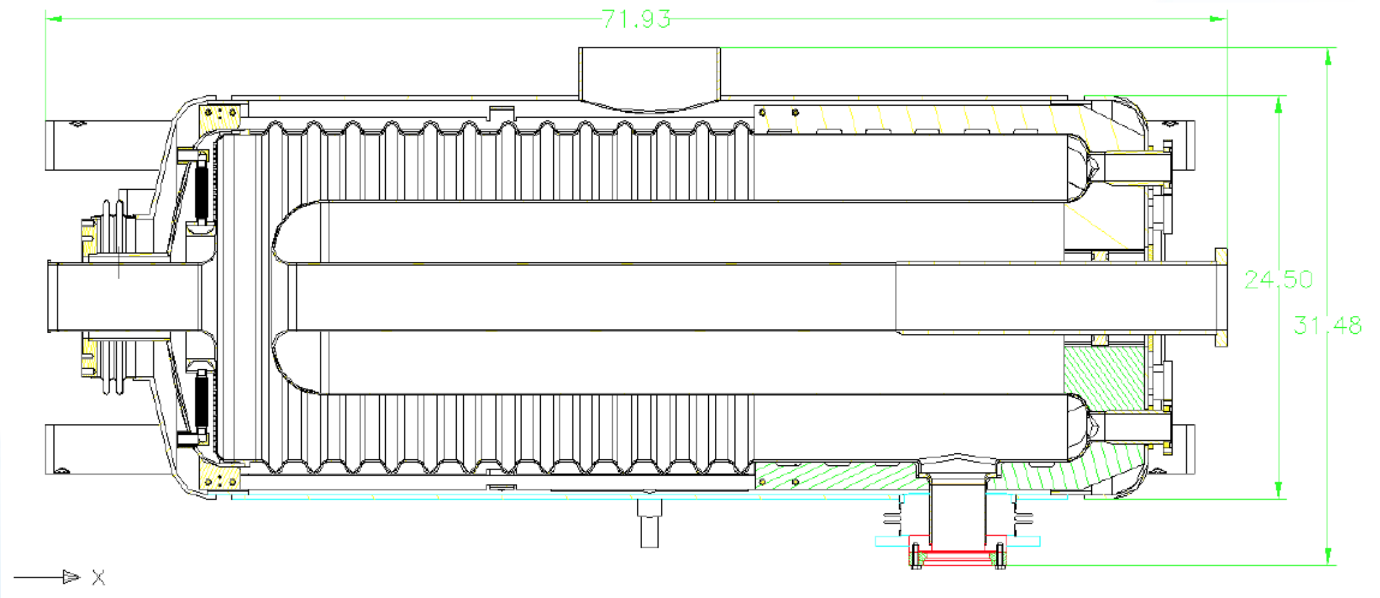
Introduction



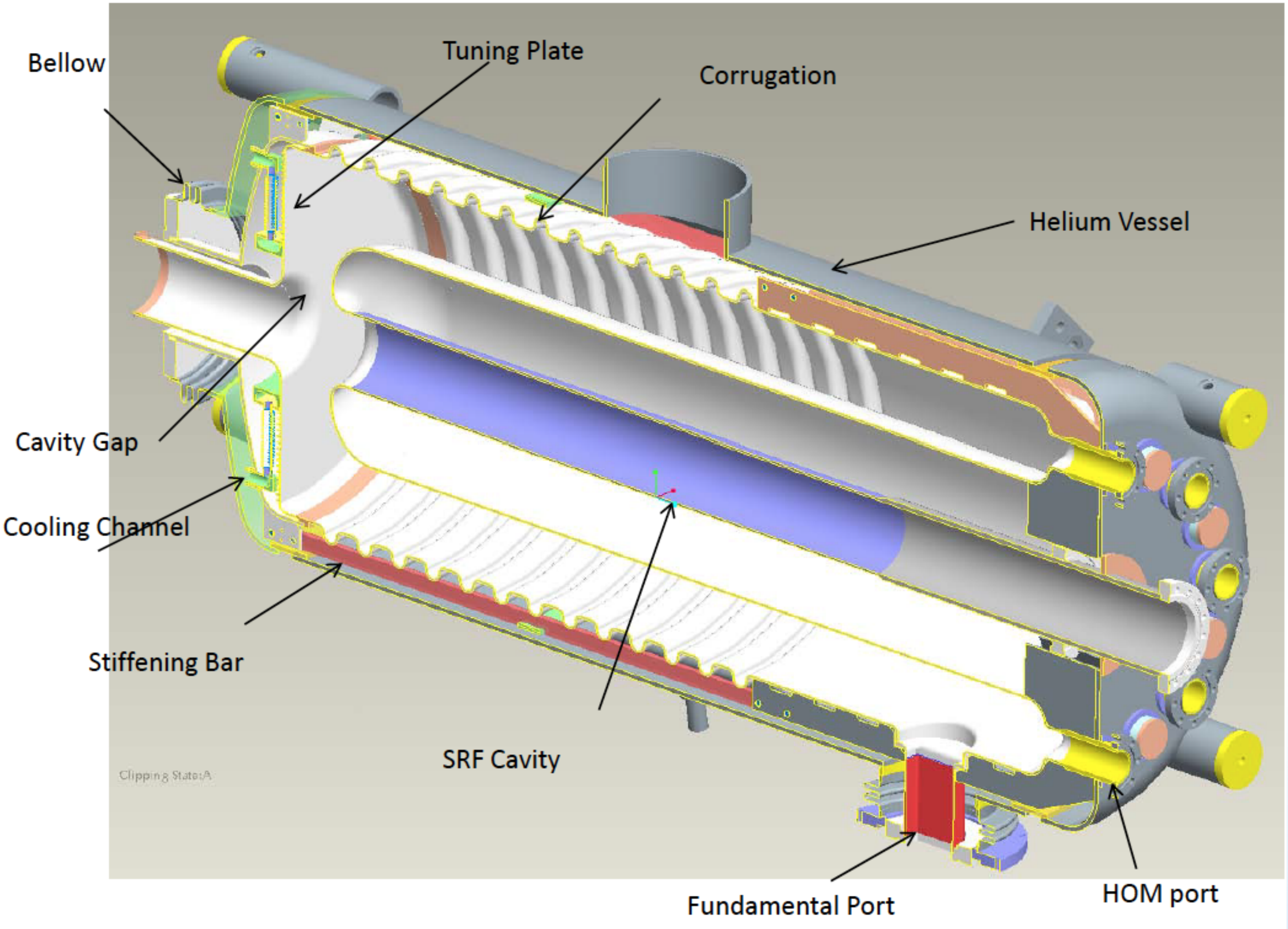
- A quarter-wave superconducting 56 MHz cavity is under construction at C-AD as an Accelerator Improvement Project (AIP).
- Its purpose is to provide a larger RF bucket (5 times larger than that of 197 MHz cavities) for particles, which should result in higher luminosity of RHIC by: direct adiabatic capture from 28 MHz system, better preservation of longitudinal emittance, elimination beam spillage in satellite buckets.
- This is a “storage” cavity, that is it does not have tuning range large enough to follow the frequency change during acceleration from the injection energy to the energy of experiment and is turned on only after acceleration for re-bucketing.
- One 56 MHz cavity will serve both RHIC rings. It will be the first superconducting RF system in RHIC.
- The 56 MHz cavity will supplement other RHIC RF systems, which currently include two 28 MHz, and one 9 MHz copper accelerating cavities, one 200 MHz Landau cavity per ring, and five 197 MHz storage cavities.
- The goal is to install it in RHIC for operations in Run-14.
- Presently, the cavity fabrication is almost complete. Fabrication of other components is beginning.

Main features of the 56 MHz cavity

- The 56 MHz cavity is tuned to 720th harmonic of the RHIC revolution frequency.
- It is a beam driven cavity.
- However, there will be a 1 kW RF amplifier. The amplifier will serve to:
  i) achieve required amplitude and phase stability;
  ii) provide conditioning capability.
- The cavity fundamental mode will be detuned and strongly damped during injection and acceleration.
- At the energy of experiment, first the fundamental damper will be withdrawn and then the cavity frequency will be tuned (approaching from below the beam harmonic) to achieve operating voltage of 2.0 MV.
- A piezo tuner will be employed to compensate any fast frequency changes.
- The 56 MHz cryomodule is compliant with ASME Pressure Vessel Code.
- Cryogens will be provided from a general purpose low-noise cryogenic system (separate AIP).



Main features of the 56 MHz cavity (2)



- The cavity is rigid: its first mechanical mode frequency is 98.5 Hz; sensitivity to the helium bath pressure is 0.282 Hz/mbar; Lorentz force detuning is -37 Hz/(MV)^2, or 148 Hz at 2.0 MV.
- The cavity is designed to be multipacting-free.
- High degree of HOM damping is provided by 4 dampers asymmetrically placed at the "short" end of the cavity.
- Fundamental mode Damper (FD) reduces the cavity fundamental mode Q to ~300 during beam injection and acceleration.
- The cavity shape was optimized so that at 2.0 MV we get E_{pk} = 35.3 MV/m, B_{pk} = 83.9 mT, power dissipation < 20 W.
- These numbers are below what was already achieved on SPIRAL2 QWR at 88 MHz: 62 MV/m; 112 mT; 4.5 Hz/mbar; -1.58 Hz/(MV/m)^2, equivalent to 191 Hz at 11 MV/m.

Mar’2011 review of the project

- A review of the project was held earlier this year, on March 8-9. The committee included both external and BNL experts: John Weisend (FRIB, MSU, Chair), Charlie Reece (SRF Institute, JLab), Jim Rose (NSLS-II, BNL), Jon Sandberg (C-AD, BNL), Joe Tuozzolo (C-AD, BNL).
- At that point: the engineering detailed design was nearly complete; the cavity / helium vessel were ordered from Niowave; procurement of other components was about to begin.
- The committee was requested to check if the cost and schedule are reasonable; evaluate design of the cryomodule and its major components and the cavity fabrication progress; review the design of HOM and fundamental dampers, FPC; evaluate the use of IR detector for quench protection; review RF and vacuum sub-systems; comment on any open technical risks and additional steps needed to answer these risks.
- From the final report: “The committee was impressed by both the scope and quality of the work done to date. While much work needs to be done and challenges remain, the committee feels the project is on the right track to meeting its scope within cost and schedule. We found no potential show stoppers other than those already identified by the project.”
- We will present the committee recommendations and our response to them below.

Response to the recommendations

1. Ensure that BNL understands and will commit to providing you with the necessary resources to meet your schedule. Produce a manpower loaded schedule and merge it into a broader one that includes all other BNL activities that may affect your resources. Explicitly track the progress of the VTA refrigerator.

    - C-AD is currently working on resource loaded schedules for the department, which will eventually include all projects. 56 MHz projects will be among first ones to be complete.

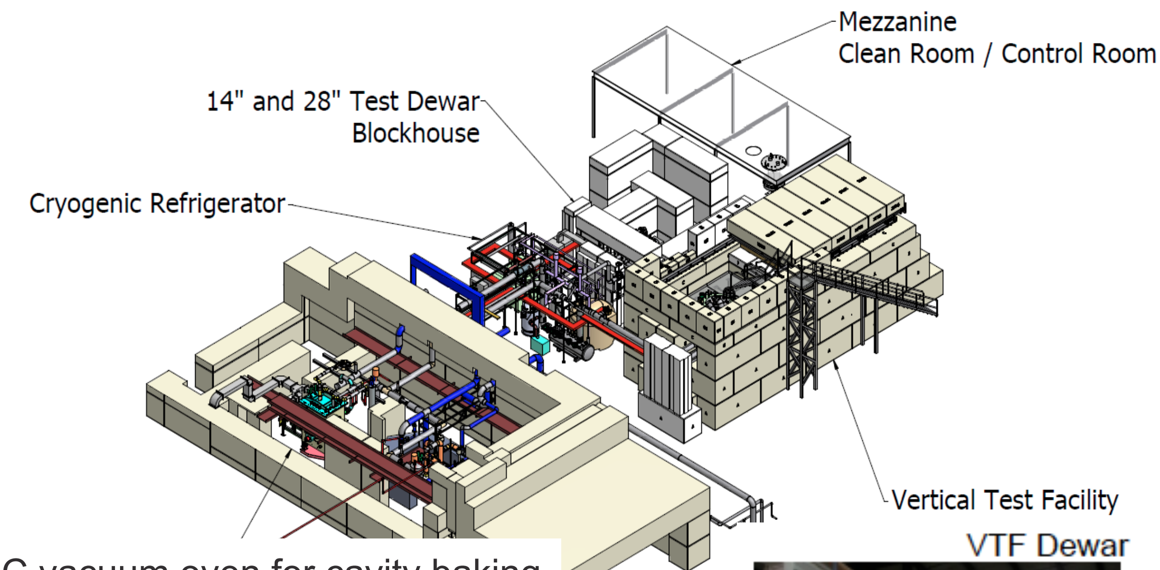
2. Facilities for SCRF (clean rooms, assembly and test areas) should continue to be upgraded. While there appear to be work-arounds that will let this project move forward, additional dedicated facilities will improve efficiency, reduce risk and help ensure appropriate quality of construction. Later SCRF projects will also benefit from this investment.

    - The Mezzanine cleanroom will be operational in December (vendor: Cleanrooms West). The vacuum furnace is on site and will be commissioned soon. LBH is ready for SRF cavity tests. VTF will be ready in time for the first vertical test of 56 MHz cavity.

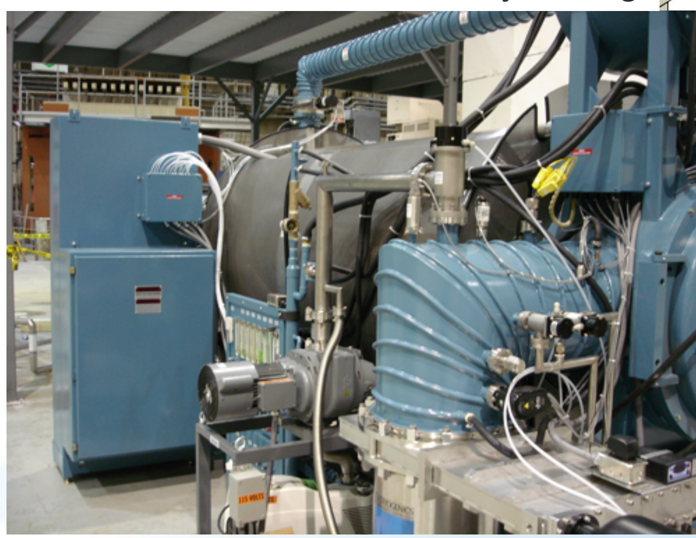
SRF test facilities in building 912

VTF Refrigerator

Layout of Accelerator R&D Facility in Building 912



800°C vacuum oven for cavity baking



VTF Dewar

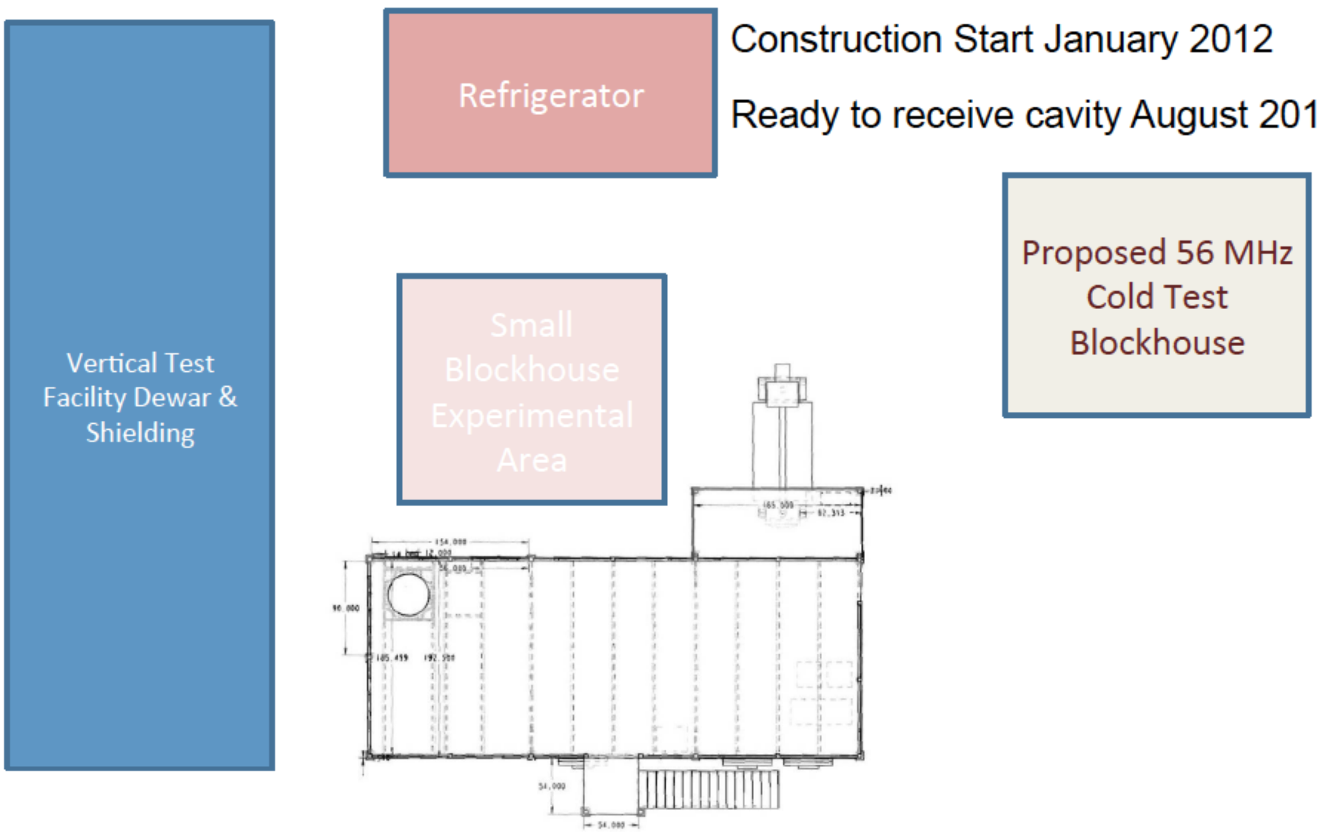
Cryomodule horizontal cold test blockhouse

Cryomodule Horizontal Cold Test
Near BLG 912 Mezzanine Area

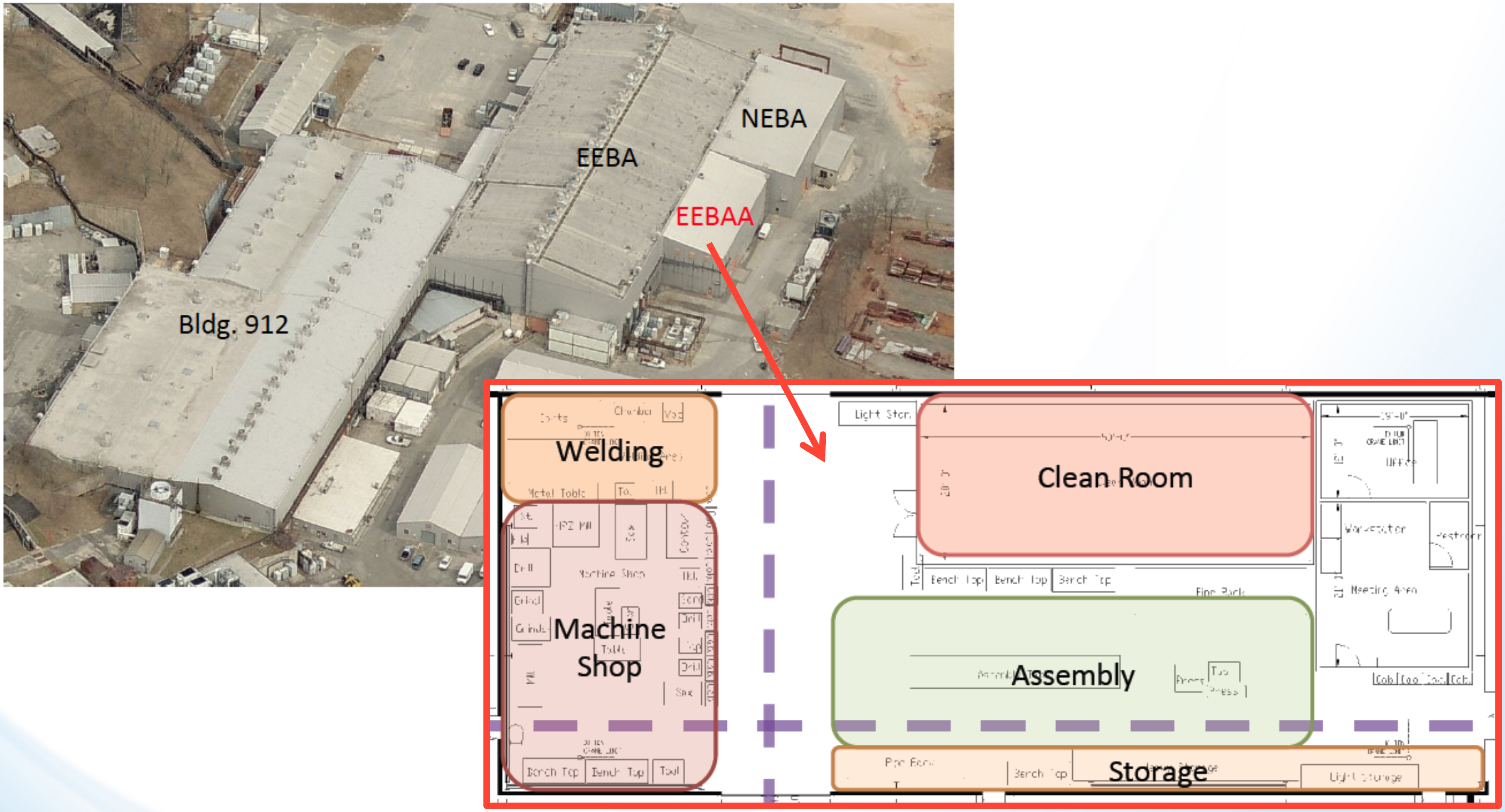
Layout to Start September 2011

Construction Start January 2012

Ready to receive cavity August 2012



Future:
SRF Cryomodule Assembly Area / Technical Shop



Recommendations on HOM coupler

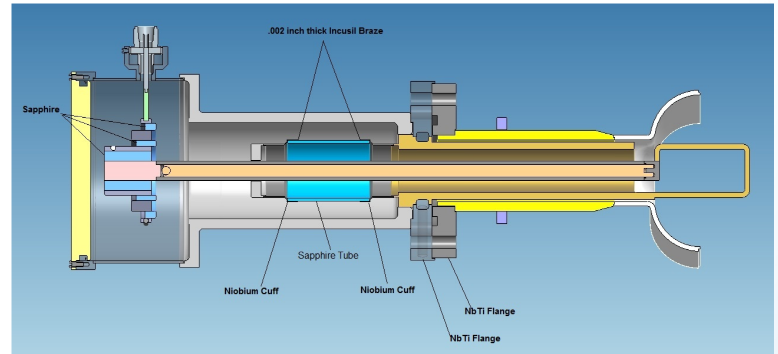
3. Given the high risk of the HOM damper design (issues with potential multipacting, thermal environment, materials, etc.) a workshop or external review strictly on the HOM damper involving other members of the SCRF community is highly recommended.
4. The HOM design should be checked with the anisotropic characteristics of dielectric and coefficient of linear thermal expansion constants of sapphire.
5. Additional multipacting studies on the HOM damper should also be carried out. This should include the study of whether coating of the sapphire window needs to be carried out to bleed charge and/or prevent multipactor.
6. Develop an experiment with the HOM coupler and cavity in the vertical test facility that closely mimics the actual cooling techniques and operating conditions (particularly thermal ones) of the HOM coupler.
7. Evaluate whether use of simple temperature diodes on the Nb surface in insulating vacuum on the cooling conduction path would provide a more reliable and economical source of HOM damper quench interlock. Also, include consideration of how the cavity loaded-Q will change with normal-conducting HOM loop and how the FPC RF control system might promptly sense that and provide an independent interlock condition.

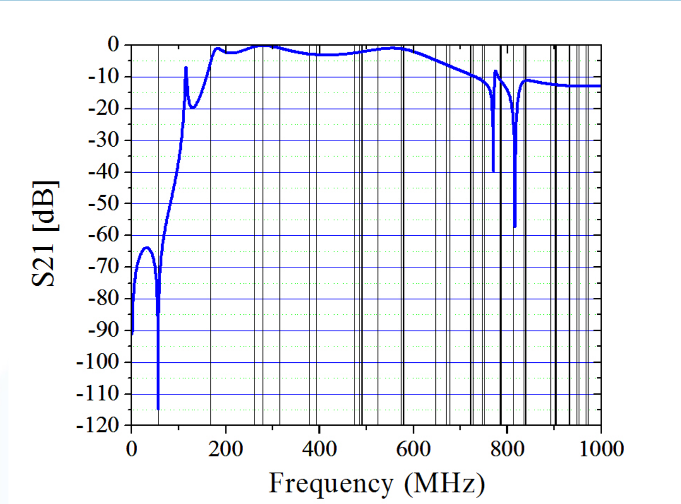
Response to recommendations on HOM coupler

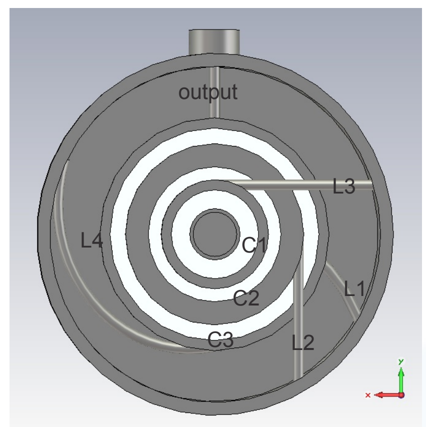
- HOM coupler has undergone significant re-design to improve cooling. We are quite confident now that the design is adequate.
- The sapphire parts will be ordered with a specific crystal orientation and its anisotropic properties are being taken into account.
- Multipacting studies are under way.
- Effectiveness of HOM damping will be checked on a copper model of 56 MHz cavity with the first article HOM coupler. One HOM coupler will be installed on the cavity for the second vertical test. The installation will closely mimic operating conditions in the cryomodule.
- Two IR sensors will be installed for the second vertical test as well to test quench detection. Analysis showed that the response time of temperature diods installed outside the HOM coupler is too slow to adequately protect against a quench. Work continues on the IR detector. As the cavity is beam-driven, RF control loop will not be sensitive to change of loaded Q.
- However, quench will be accompanied by sudden RF power increase on 28 MHz cavity. This may be used for quench detection.

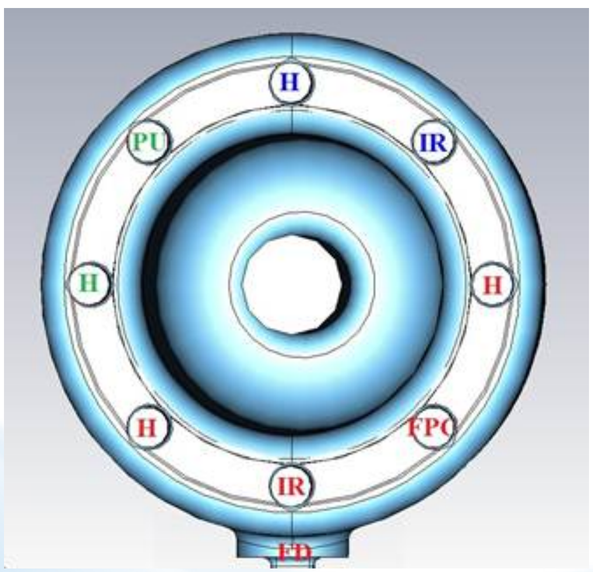
HOM coupler design (RF)

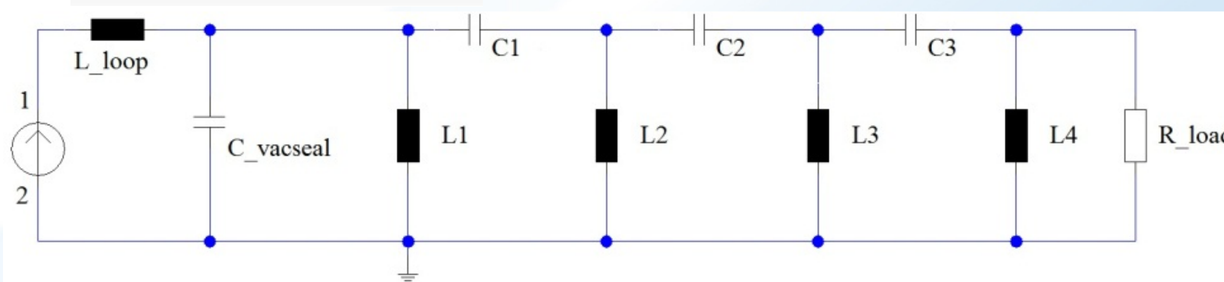
- With optimization to all HOM modes up to 1 GHz, the cavity will have 4 HOM dampers. The 4 dampers are inserted in an asymmetric configuration, which ensures all modes can be extracted to a certain degree.
- The filter provides -110 dB attenuation at -56.3 MHz, which limits the output power of the fundamental mode to less than 1 mW.
- The total power of the HOM modes excited by the beam in the 56 MHz SRF cavity is ~1.1 W/damper during operation, both rings are included. With the filter installed, the HOM total power output is ~0.33 W/damper.



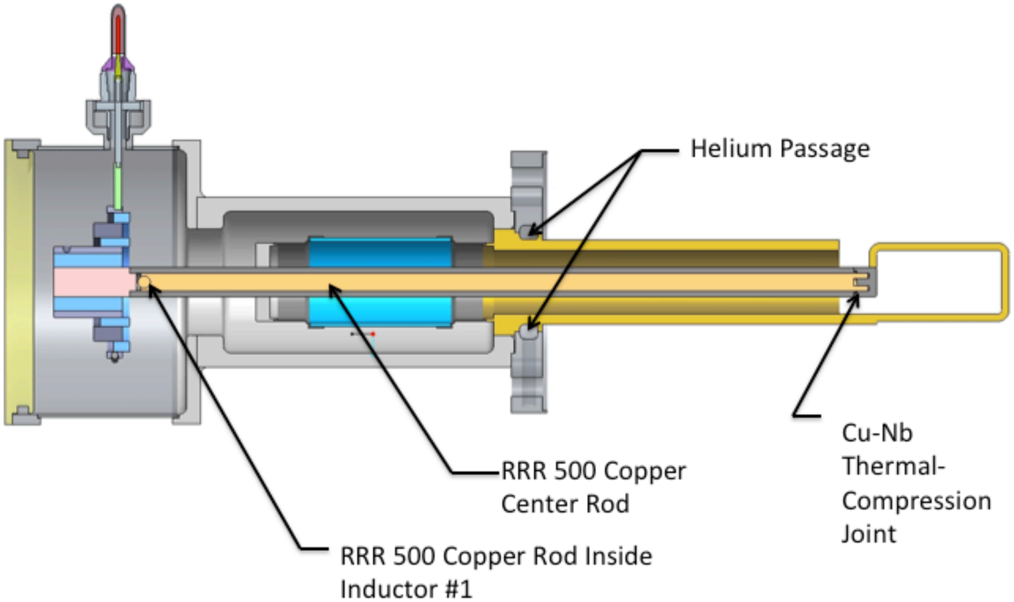


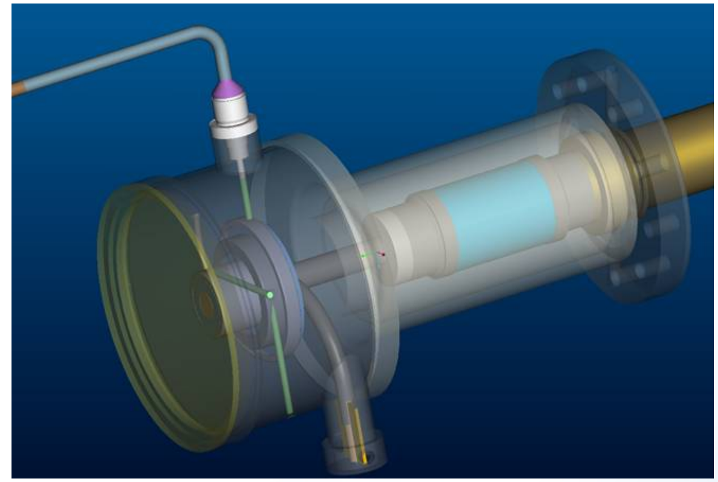




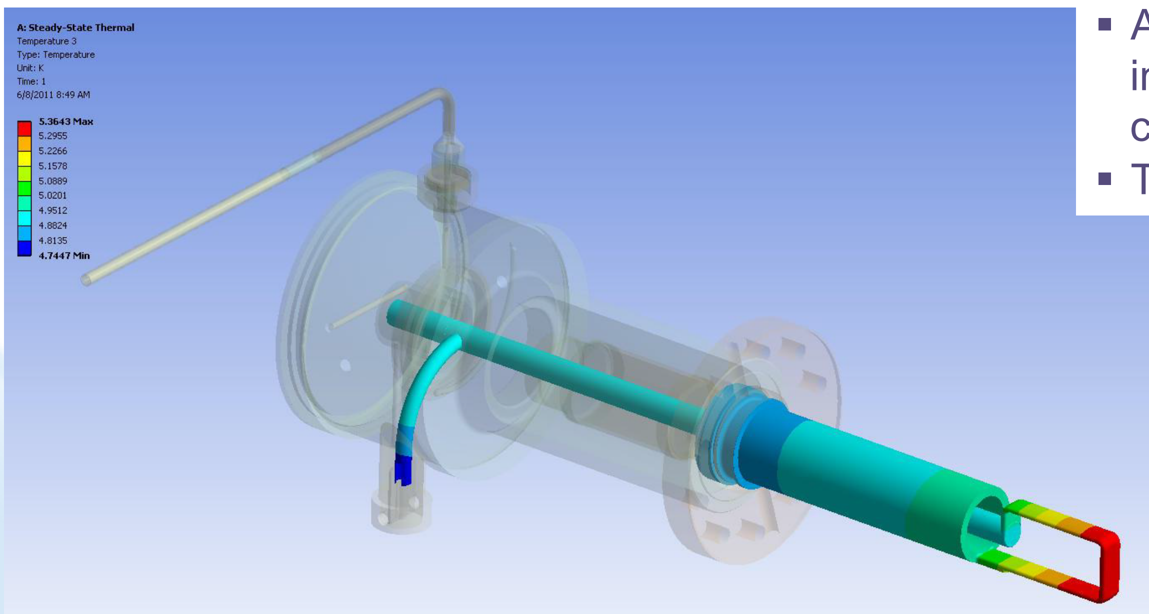


HOM coupler thermal analysis



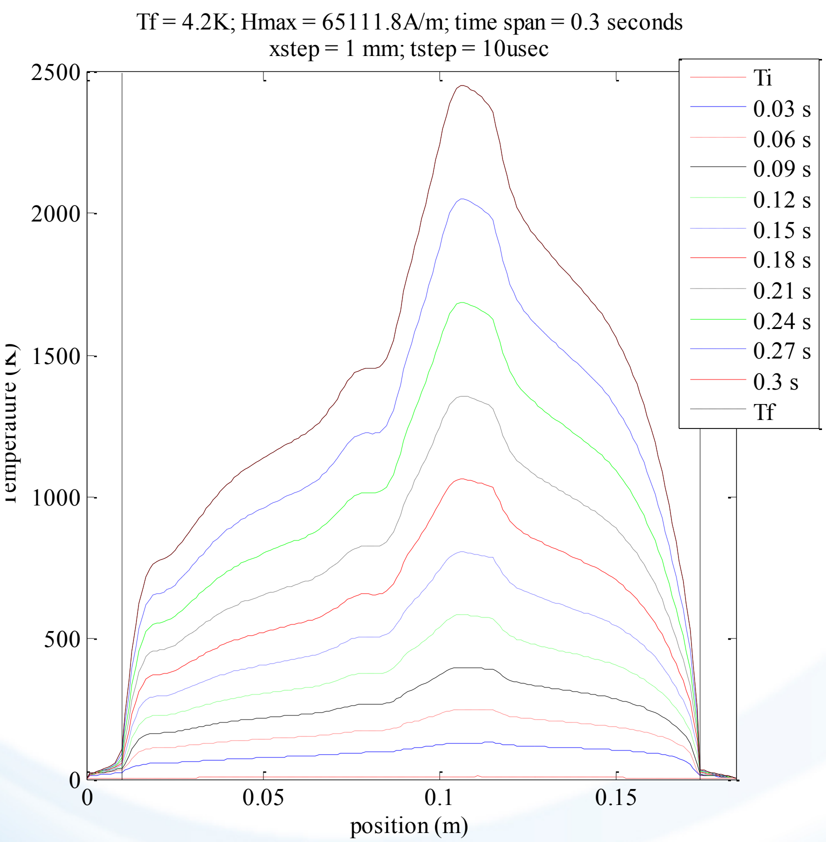


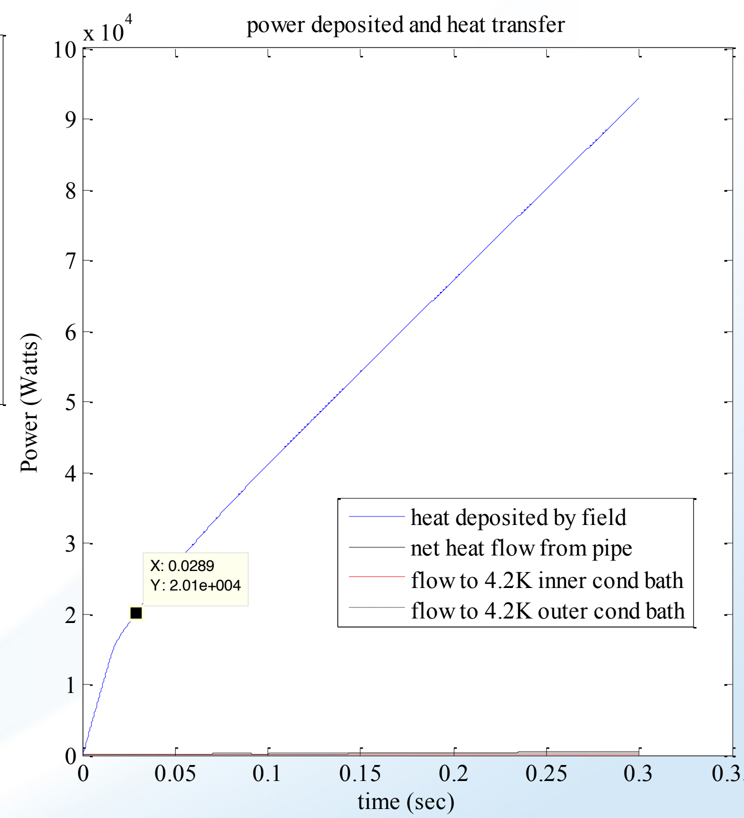
- The NbTi flange will be cooled with helium.
- A high RRR copper rod will be used inside the center conductor to improve cooling of the loop.
- The copper rod will be cooled by LHe.



HOM coupler quench analysis

- If unlimited power were available to the beam, we would start to see IR signal after 90 ms, and the loop would start melting after 300 ms.
- The dissipated power reaches 20 kW in ~ 30 ms. This power would be drawn from the RHIC 28 MHz system. The sudden power increase is an indication of quench.





Response to the recommendations (2)

8. It is strongly recommended to construct a dummy cavity from inexpensive materials with similar mass and interface points. The dummy cavity should be used to commission handling procedures, HPR procedures, and clean assembly procedures (including coupler insertion and mounting without cavity contact or particulate generation).

   - Processing equipment will be tested using mock-up components, and procedures will be verified prior to actual processing. A full size dummy cavity will not be fabricated for a single component run.

9. Specific test criteria that indicate success should be developed for each major component.

   - HOM coupler will be tested with the cavity in VTF. RF windows will be tested at room temperature to full power. Test criteria for other major components are under consideration.

Response to the recommendations (3)

10. Consider the use of formed rather welded bellows in the FPC.
11. Analyze the HOM field penetration into the coaxial region formed by the FPC port and loop outer conductor.

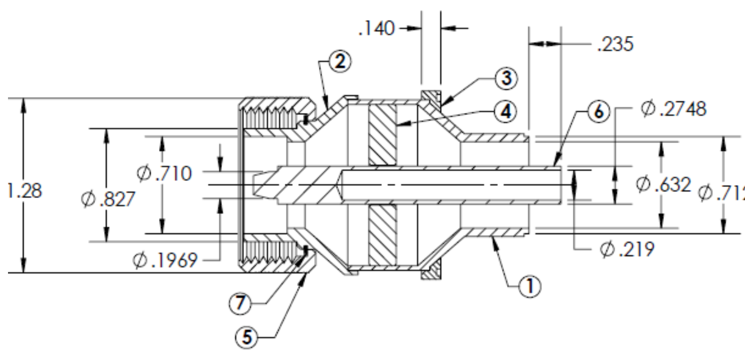
- Welded bellows are used to provide the required coupling range of FPC.
- As the HOMs are extremely well damped, the HOM field in the coaxial region formed by the FPC port and loop outer conductor is negligibly small. The same is true for other ports (FD, RF pick-up, HOM).

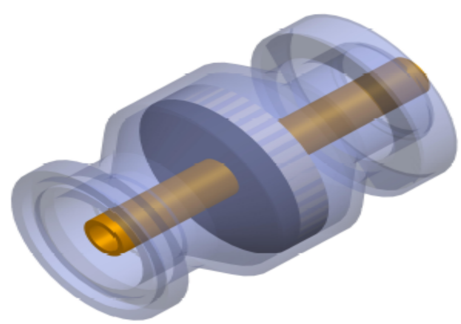
12. Investigate the impact on radiation damage on the on the proposed optical encoder.
13. Review use of press fits on the coaxial cables and potential impact of differential thermal contraction upon cool down.

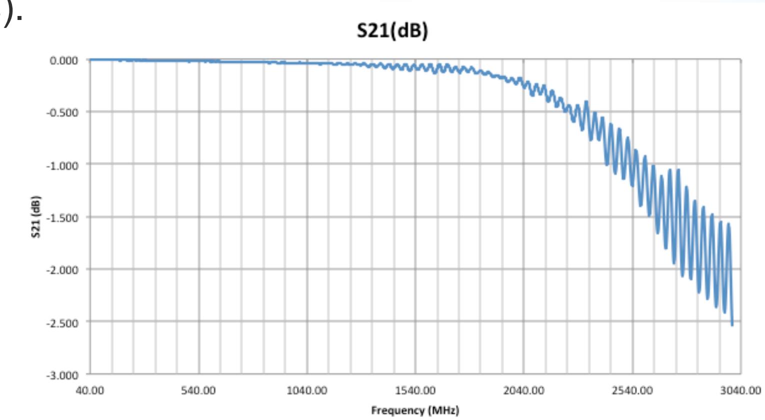
- A radiation-hard optical encoder will be used.
- A study has been initiated regarding the impact of differential contraction during cooldown.

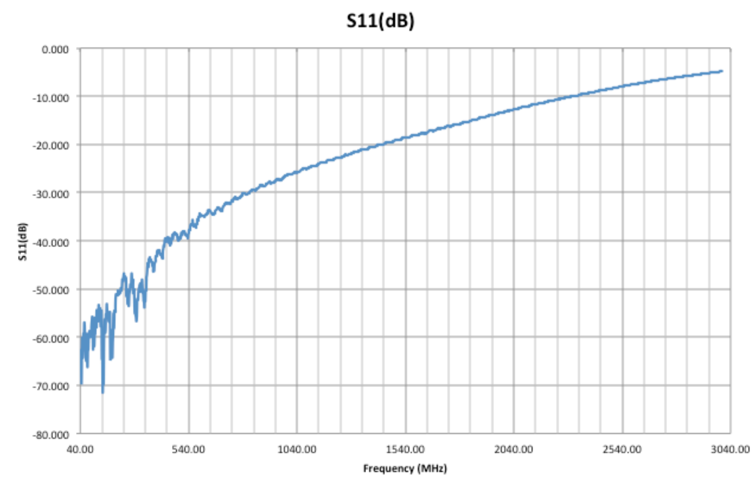
RF windows for FPC and FD

- New wide-band RF window was designed for 56 MHz FPC, FD and for ERL large grain gun test (704 MHz).
- RF design was done at BNL, mechanical design was developed in collaboration with MPF. MPF has fabricated two “first article” units.
- Two designs: double- and single-ended (7-16 DIN connectors).
- RF measurements confirmed wide bandwidth of the design.
- It will be tested at 56 MHz from a 1 kW amplifier.









Project status

- Cavity fabrication is under way at Niowave, nearly complete.
- HOM coupler design is complete.
- RF windows for FPC, FD, HPM couplers are designed and are on order from MPF. Two “first article” windows have been delivered for testing. RF measurements are good.
- 1 kW CW RF amplifier has been tested to full power.
- Vacuum furnace for 600°C to 800°C cavity bake is delivered, utilities tie up is in progress.
- Mezzanine cleanroom for VTF assembly is on order from Cleanrooms West. Scheduled to be installed by the end of the month.
- VTF PASS wiring should be complete soon.

Project milestones

▪ Cavity fabrication complete	11/21/11
▪ Mezzanine cleanroom installed and certified	12/15/11
▪ Cavity vacuum firing & bulk processing complete	01/23/12
▪ Helium vessel attached & tested	04/11/12
▪ First vertical testing	05/14/12
▪ Vertical testing complete	06/28/12
▪ Cryomodule assembly complete	12/12/12
▪ Horizontal cold testing complete	07/16/13
▪ In-RHIC installation complete	09/16/13

Cavity integration in RHIC

- The complete 56 MHz cavity will be tested in a horizontal test block house prior to installation in RHIC. This will allow to debug sub-systems and components.
- About one-week-long dedicated commissioning time in RHIC is anticipated upon installation.
- The cavity can be turned safely off, detuned to “home” position with the FD inserted to become “transparent” to beam.
- Off-normal events (cavity quench, cryogenic problems, vacuum events, multipacting, etc.) will initiate a beam dump.

Acknowledgements

I would like to thank all C-AD personnel who participate in the 56 MHz project.